



WHAT IS NEEDED FOR PRECISION MEASUREMENTS AT LBNF?

Elizabeth Worcester (Brookhaven National Lab)

Workshop on the Intermediate Neutrino Program, 3 February 2015

Overview

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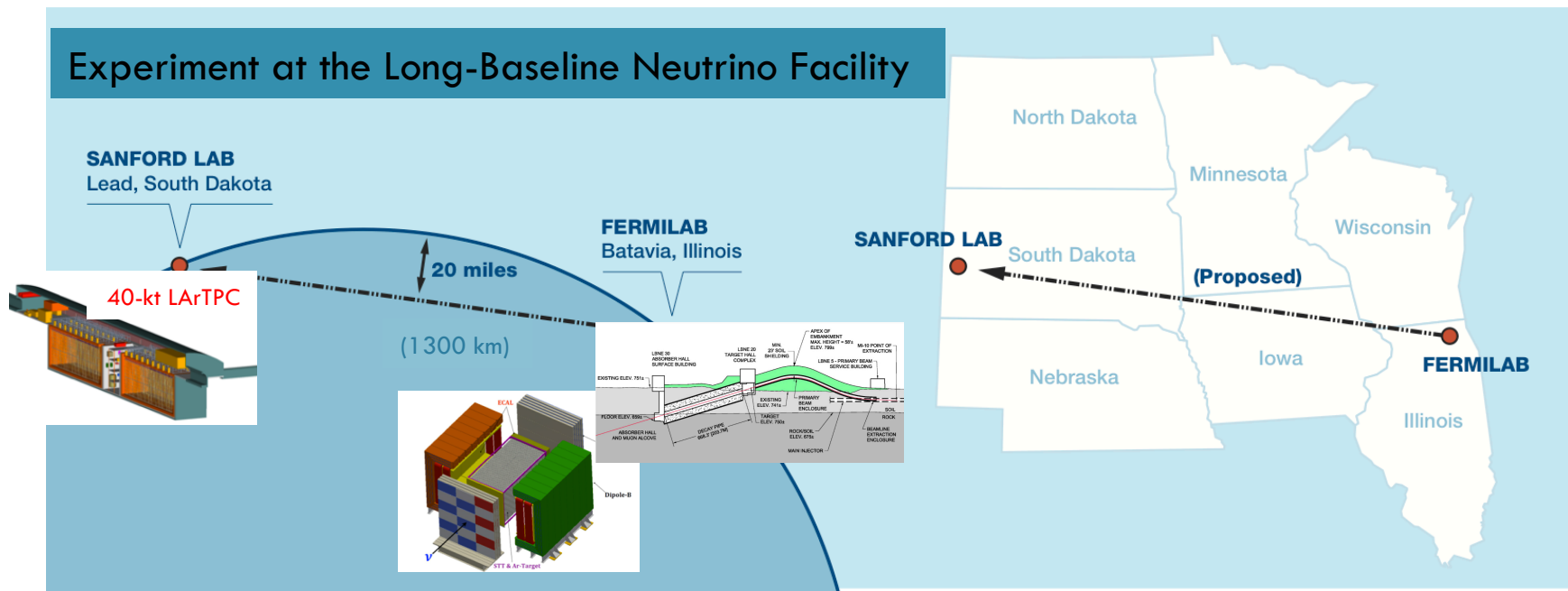
- ELBNF Introduction
- Detector R&D
- ELBNF Experiment Optimization
- Constraining Systematic Uncertainty
- Sociology

“The opinions expressed in this talk are not necessarily those of the ELBNF collaboration...”

Experiment at the Long-Baseline Neutrino Facility

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- Broadband neutrino beam from FNAL to SURF
 - ▣ 1300-km baseline
 - ▣ >1 MW of 60-120 GeV protons from upgraded Main Injector (PIP-II)
 - ▣ New μ -neutrino beam line
- Precision near detector
 - ▣ 40-kt LAr TPC
 - ▣ Integrated optical photon detection system



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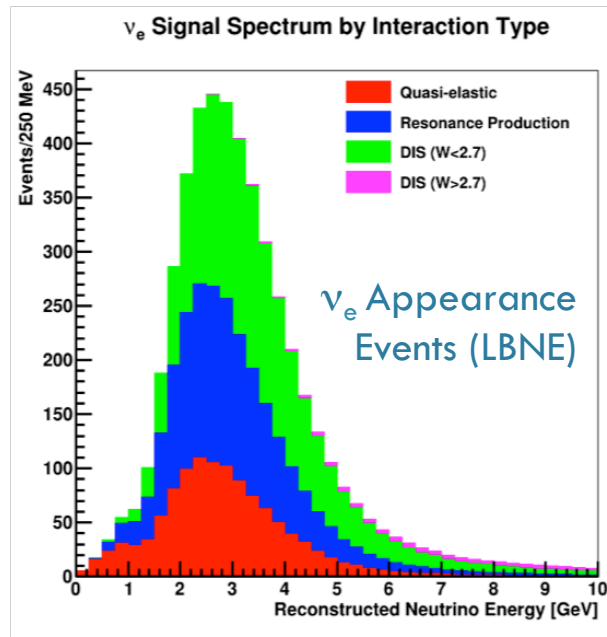
ELBNF Collaboration Status

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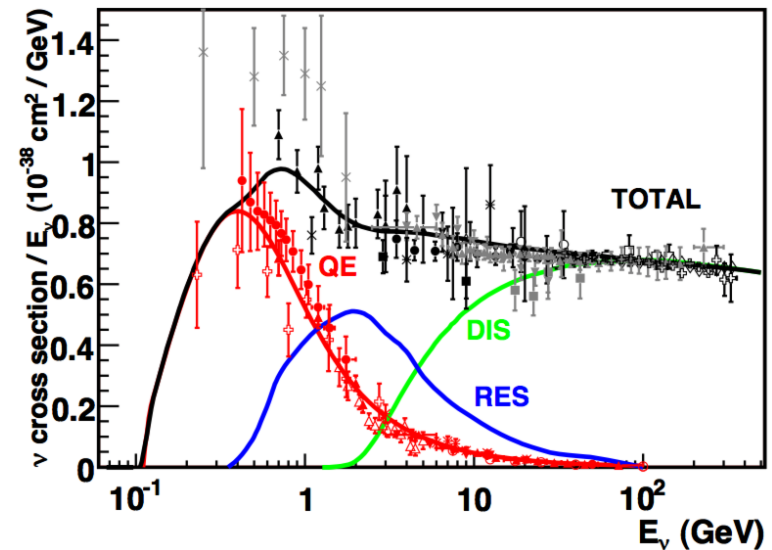
- Letter of Intent:
 - ▣ Presented to FNAL PAC in January 2015
 - ▣ http://www.fnal.gov/directorate/program_planning/Jan2015Public/LOI-LBNF.pdf
- Proto-Collaboration Meeting:
 - ▣ January 22-23, 2015
 - ▣ First IB meeting with >65 institutions represented
 - ▣ Memorandum of collaboration passed, plans in place for election of spokespeople, creation of international collaboration governance document, appointment of working group conveners, naming contest, etc...
 - ▣ <https://indico.fnal.gov/conferenceDisplay.py?ovw=True&confId=9209>
- Expect CDR in 2015
- See M. Mooney in “3v mixing” session tomorrow morning

Neutrino Events at ELBNF

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Significant contributions to event sample from QE, RES, DIS



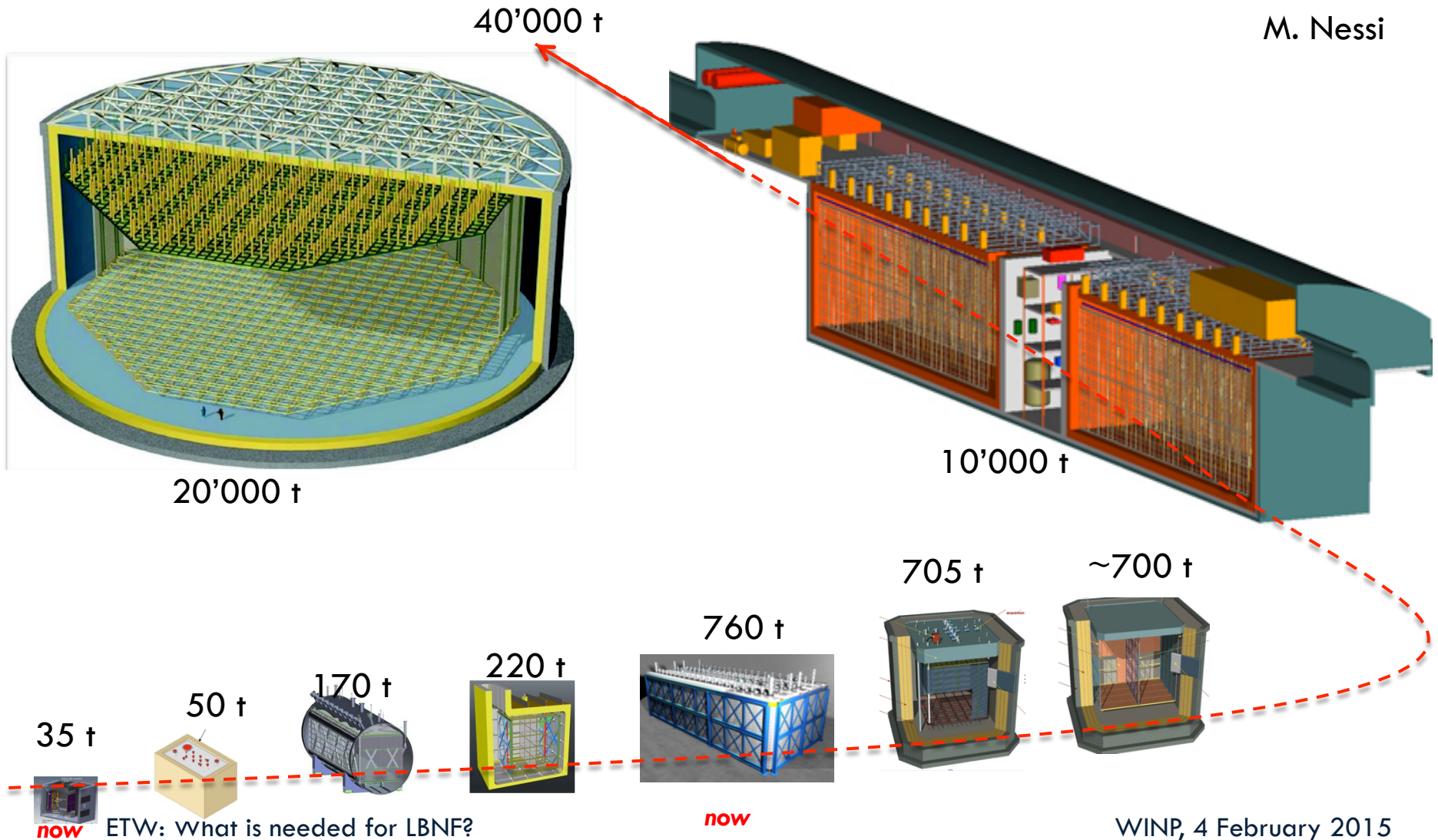
Run Mode	Signal Events			Background Events			
	$-\pi/2$	δ_{CP} 0	$\pi/2$	ν_μ NC	ν_μ CC	ν_e Beam	ν_τ CC
Neutrino	1068	864	649	72	83	182	55
Antineutrino	166	213	231	41	42	107	33

Exposure: 257 kt.MW.yr =
40 kt x 1.07 MW (80-GeV) x
($3\nu + 3\bar{\nu}$) years

LArTPC R&D

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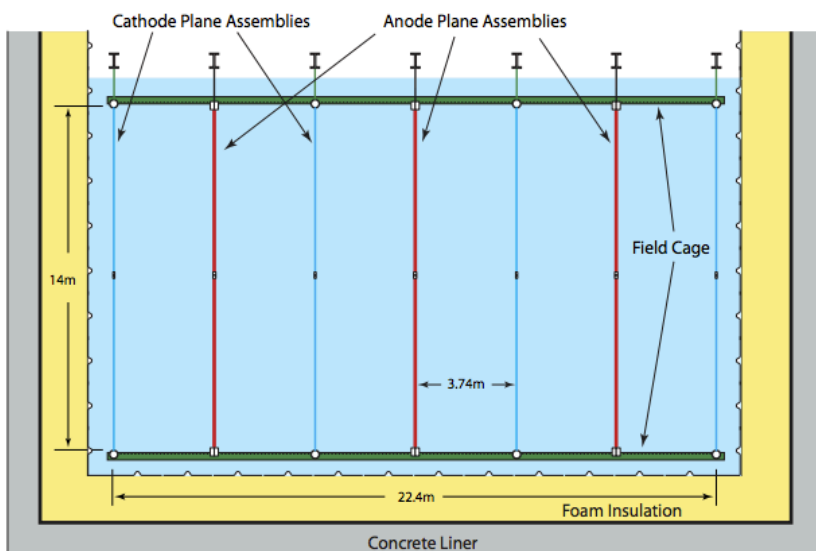
M. Nessi



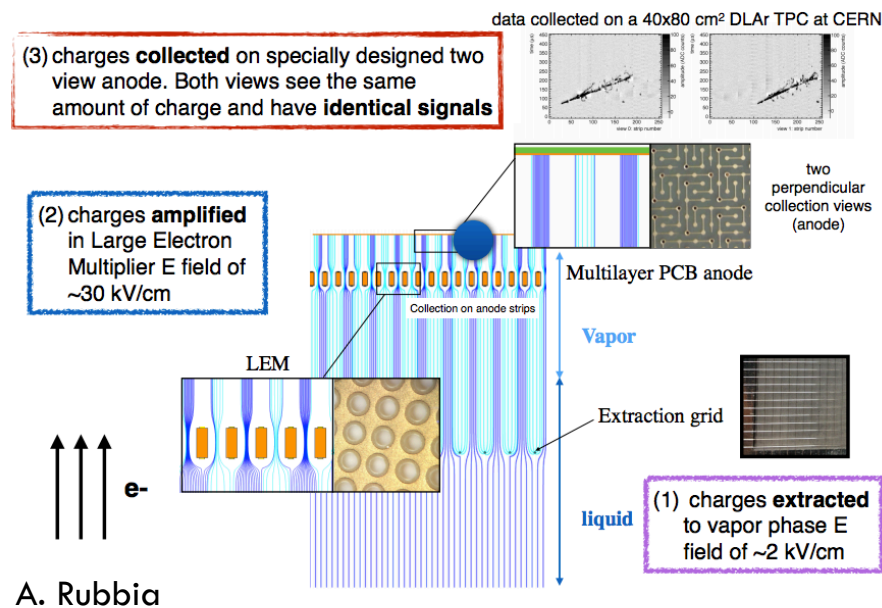
ELBNF LArTPC Designs

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- Single phase:
 - ▣ Modular “anode plane assembly” (APA) wire readout hangs inside LAr volume
 - ▣ Wires wrap around APA to read out multiple drift volumes



- Dual phase:
 - ▣ Fully active LAr volume
 - ▣ Ionization electrons drift in E-field to top of detector where they are amplified in a gas phase and collected



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LArTPC R&D

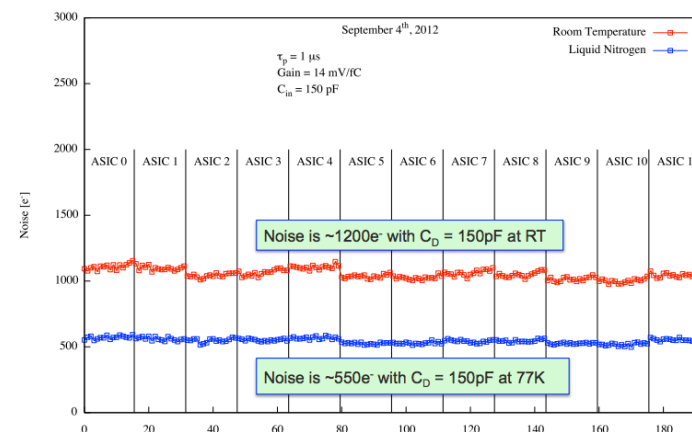
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- Purification/electron lifetime (C. Thorn*)
 - 3 ms electron lifetime requires impurity ~ 100 ppt
 - LBNE design: maximum drift time > 2 ms
- Cold electronics (V. Radeka*)
 - Lower noise and reduced cable plant
 - μ BooNE: cold ASICs
 - LBNE 35-t prototype: full readout chain
- High voltage (S. Lockwitz*)
 - μ BooNE design: 500 V/cm with 2.5-m drift
 - LBNE design: 500 V/cm with 3.4-m drift
- Photon detection (M. Toups*)
 - t_0 for non-beam physics and improved charge/position reconstruction
 - Improved calorimetry
 - Scintillation light emitted at 128 nm
- Affect single- and dual-phase designs differently

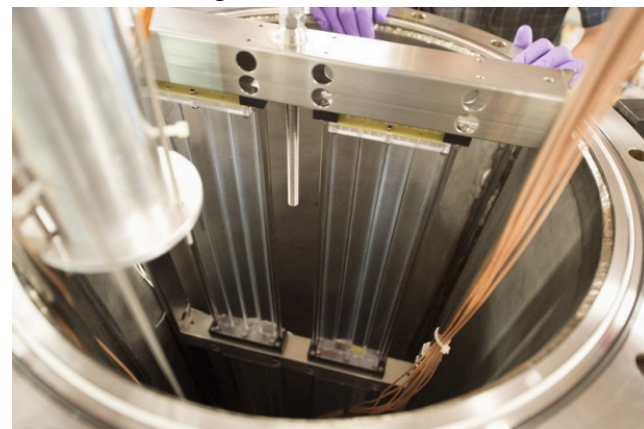
***See talk in R&D session tomorrow afternoon**

H. Chen

Noise vs. Temperature: 12 ASICs (192 channels)



D. Whittington



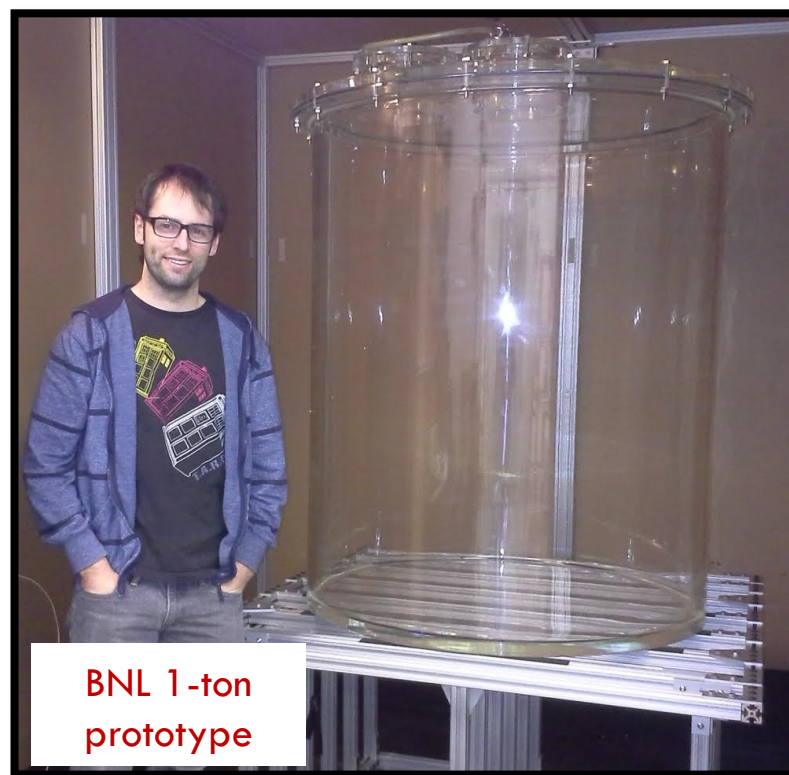
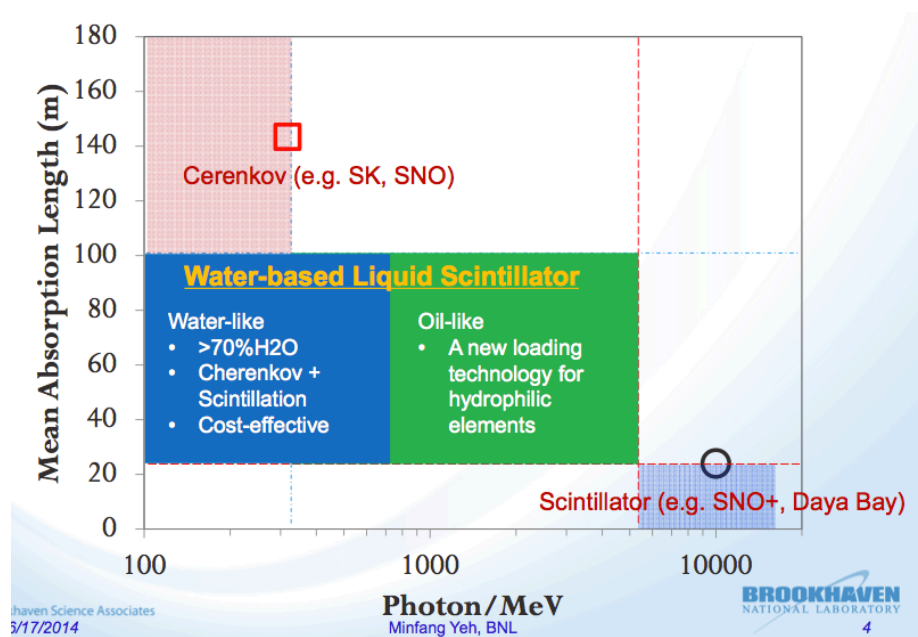
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Future LBNF Detector: WbLS R&D

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- ❑ **Water-based Liquid Scintillator** (see M. Yeh in R&D session tomorrow)
- ❑ Combines benefits of water and liquid-scintillator detectors in single medium
 - ▣ High light yield and low threshold of scintillator
 - ▣ Longer absorption length and ring-imaging capability of water
 - ▣ Tunable scintillation timing profile
- ❑ Facilitates metal loading



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Future LBNF Detector: Theia^{*Goddess of Light}

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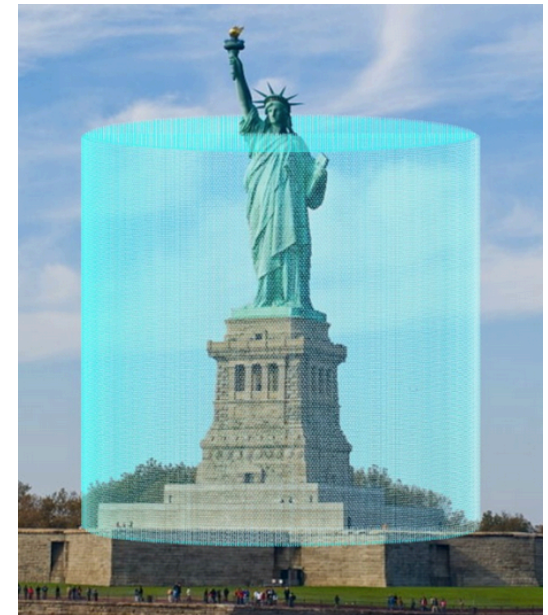
- Large WbLS detector at LBNF far site has potential to study
 - ▣ Long-baseline neutrino oscillation
 - ▣ Neutrinoless double beta decay
 - ▣ Solar neutrinos
 - ▣ Geo-neutrinos
 - ▣ Supernova neutrinos
 - ▣ Diffuse supernova background neutrinos
 - ▣ Nucleon decay
 - ▣ Sterile neutrinos
- Physics potential enhanced by fast photo-sensors and high, granular photo-coverage (LAPPDs?)
- Theia: A realization of the Advanced Scintillator Detector Concept (see G. Orebi Gann in “**properties**” and R. Svoboda in “**3v mixing**” sessions tomorrow morning)

arXiv:1409.5864

Advanced Scintillator Detector Concept (ASDC):

A Concept Paper on the Physics Potential of Water-Based Liquid Scintillator

J. R. Alonso,¹ N. Barros,² M. Bergevin,³ A. Bernstein,⁴ L. Bignell,⁵ E. Blucher,⁶ F. Calaprice,⁷
J. M. Conrad,¹ F. B. Descamps,⁸ M. V. Diwan,⁵ D. A. Dwyer,⁸ S. T. Dye,⁹ A. Elagin,⁶
P. Feng,¹⁰ C. Grant,³ S. Grullon,² S. Hays,⁵ D. E. Jaffe,⁵ S. H. Kettell,⁵ J. R. Klein,²
K. Lande,² J. G. Learned,¹¹ K. B. Luk,^{5,12} J. Maricic,¹¹ P. Marleau,¹⁰ A. Mastbaum,²
W. F. McDonough,¹³ L. Oberauer,¹⁴ G. D. Orebi Gann,^{8,12} R. Rosero,⁵ S. D. Rountree,¹⁵
M. C. Sanchez,¹⁶ M. H. Shaevitz,¹⁷ T. M. Shokair,¹⁸ M. B. Smy,¹⁹ A. Stahl,²⁰ M. Strait,⁶
R. Svoboda,³ N. Tolich,²¹ M. R. Vagins,¹⁹ K. A. van Bibber,¹⁸ B. Viren,⁵ R. B. Vogelaar,¹⁵
M. J. Wetstein,⁶ L. Winslow,¹ B. Wonsak,²² E. T. Worcester,⁵ M. Wurm,²³ M. Yeh,⁵ and C. Zhang⁵

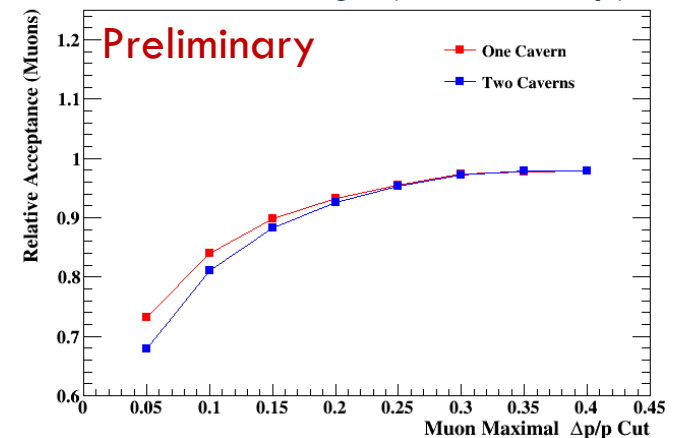


ELBNF Experiment Optimization

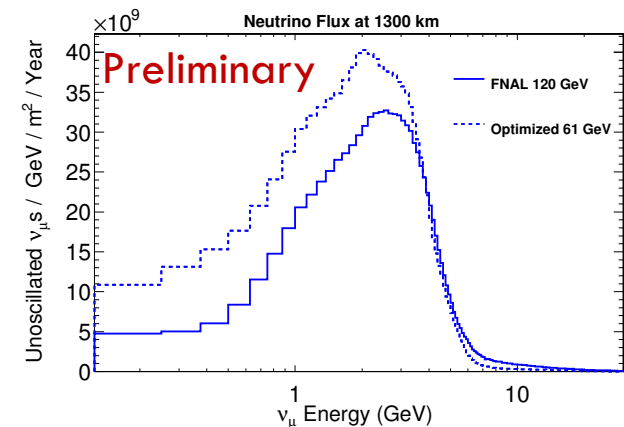
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- Far detector design
 - ▣ Single- or dual-phase LAr TPC (or both?)
 - ▣ Optimal configuration/geometry
 - ▣ Multiple far detectors (LAr TPC + WCD, ASDC, ...)
 - Combination of datasets with different systematics
 - ▣ Photon detection system
 - Optimal lightguide/WLS design
 - Benefits of increasing photon detection efficiency
- Near detector design
 - ▣ Required performance of magnetized, high-resolution ND
 - ▣ Benefits of additional “identical” LAr TPC ND
 - ▣ Benefits of muon monitors
- Beam design
 - ▣ Beam design used for nominal sensitivity calculations based on NuMI
 - ▣ Potential to optimize the beam design both by considering enhancements to NuMI design and focusing designs different from NuMI

Cavern design (M. Mooney):



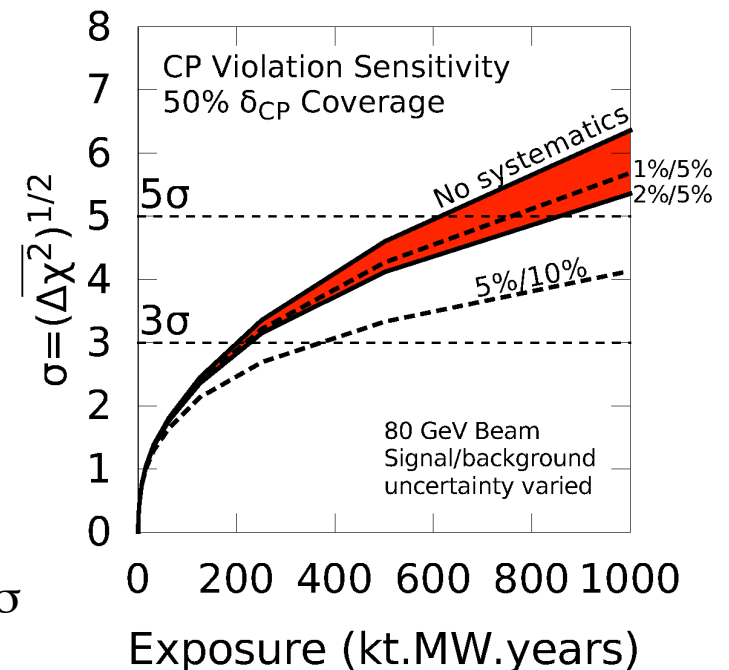
Optimized flux (L. Fields):



Systematic Uncertainty in ELBNF

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- Effect of systematics approximated using signal and background normalization uncertainties which are treated as *uncorrelated* among the modes ($\nu_e, \bar{\nu}_e, \nu_\mu, \bar{\nu}_\mu$) and represent the residual uncertainty expected after constraints from the near detector and the four-sample fit are applied
 - ▣ Actual experimental sensitivity to systematic uncertainty will depend on details of the neutrino beam and detector performance and will include both normalization and shape uncertainty
 - ▣ Example shown here illustrates that control of normalization uncertainty at the few % level will be needed for discovery of CP violation at the 5σ level
- Current ELBNF efforts focus on evaluating ability of ND and FD samples to constrain individual sources of uncertainty – sets requirements for detector performance & external constraints

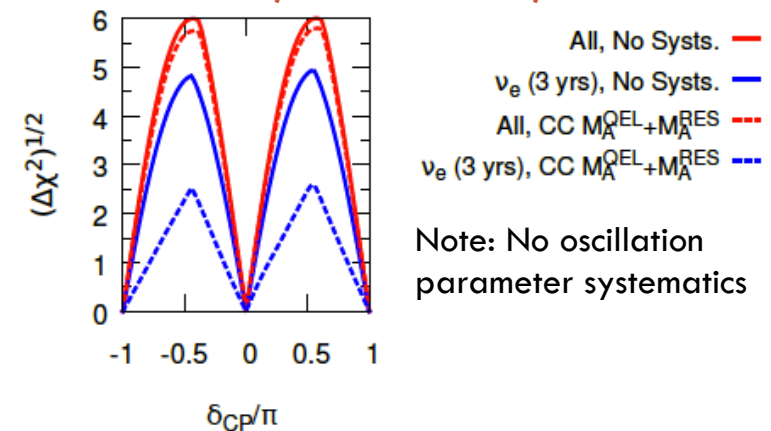


Systematics Example: Constraining Cross Sections with Far Detector

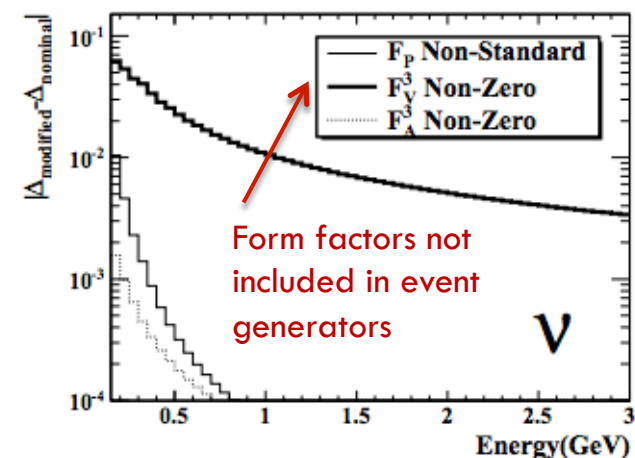
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- FastMC with **no** ND constraints
 - ▣ Vary cross-section parameters within GENIE uncertainties, eg: M_A^{QE} and M_A^{RES}
- Significant degradation in sensitivity for fit to only ν_e appearance sample for a single cross-section systematic uncertainty
- Fit to all four FD samples significantly constrains cross-section variations leading to very little degradation in sensitivity for same cross-section uncertainty
- Includes uncertainty in cross-section ratios: $\nu/\bar{\nu}$ (10%) and ν_e/ν_μ (2.5%)
 - ▣ Theory input needed
 - ▣ Cross-section measurements needed
 - eg: MINERvA ν_e QE CC cross-section (arXiv:1501.05214)

M. Bass, D. Cherdack, R. Gran




arXiv:1206.6745



Cross-section and nuclear models: Beyond current uncertainties

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- Basic strategy is to compare observables among alternative cross-section and nuclear-interaction models in GENIE
 - ▣ Long- and short-range correlations among nucleons
 - ▣ Effect of random phase approximations
 - ▣ Meson exchange currents
 - ▣ 2p-2h effects in CCQE
 - ▣ Effective spectral functions
 - ▣ Coherent pion production
 - ▣ Alternative model of DIS interactions
 - ▣ Variation of tunable parameters within existing models
 - Comparison with data (MINERvA, NOvA-ND, T2K-ND280, μ BooNE, LAr1-ND, T600, ...)
 - Comparison with alternative generators (NuWro, GiBUU)
 - Requires support for and close collaboration among model builders, developers of event generators, cross-section experiments, and ELBNF.
- 
- In various stages of implementation in GENIE.

LAr TPC: Simulation & Reconstruction

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- LArSoft: software package for simulation and reconstruction of LAr TPCs used by multiple experiments
 - ▣ Full MC simulation (single particle and neutrino interactions) available in many geometries, including wrapped-wire design
 - ▣ Fully automated reconstruction for wrapped-wire design is in progress
- Data is critical in validation/development of simulation and reconstruction techniques
- Test beam measurements of single particle response valuable input to MC
 - ▣ Test beam measurements can not (in general) be directly applied to ELBNF detectors – must use data to validate simulation over a range of detector parameters and then use MC to compare with in-situ measurements in a particular detector

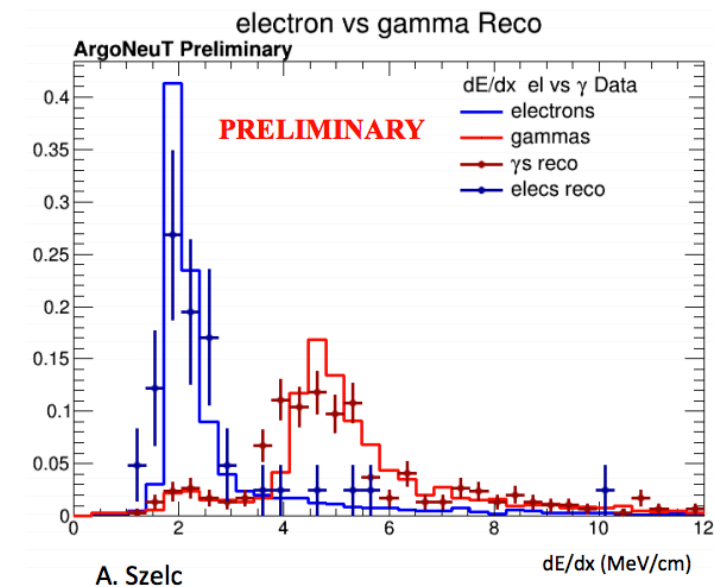
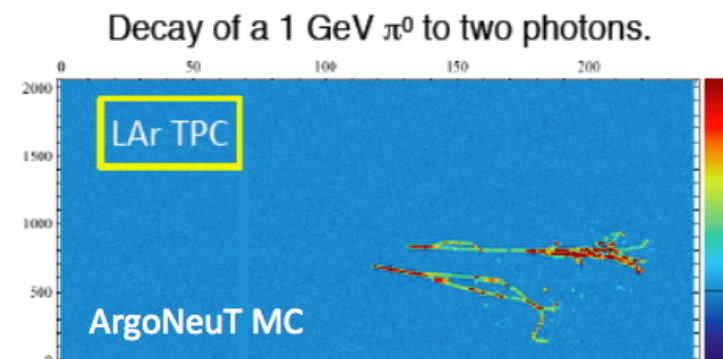


ν_e CC event in LAr TPC simulated with LArSOFT and reconstructed in 3D (PANDORA)

LAr TPC: Analysis Techniques

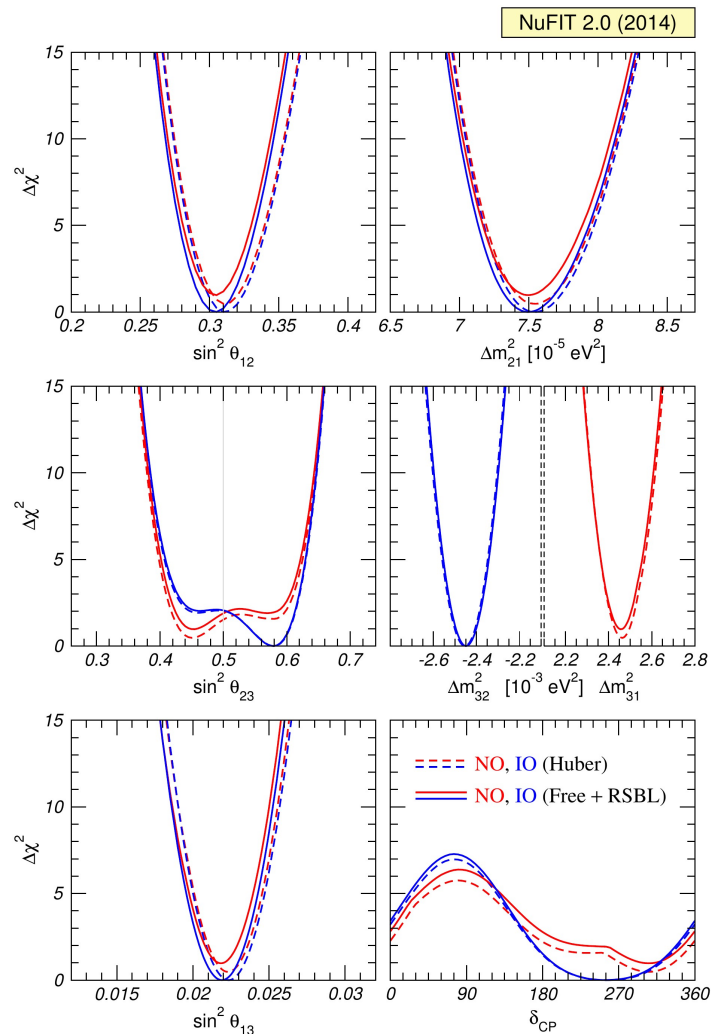
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- Ex: e- γ separation for NC background rejection
 - ▣ Current estimates in ELBNF studies based on vertex separation and dE/dx cut (μ BooNE MC)
 - ▣ dE/dx separation demonstrated in ArgoNeuT
 - ▣ Further demonstration of efficiency and fine-tuning of selection algorithm in test-beam environment and in real physics measurements needed
- Need similar analysis validation for resolution and scale corrections for multiple Coulomb scattering, EM shower reconstruction, hadron shower reconstruction, and neutron response; particle ID; energy-scale calibrations; fiducial volume requirements...



Neutrino Oscillation Parameters

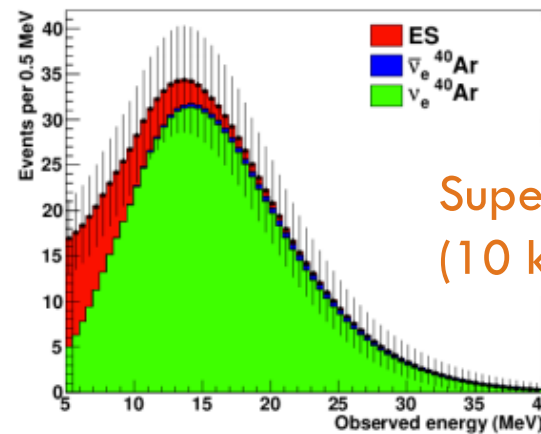
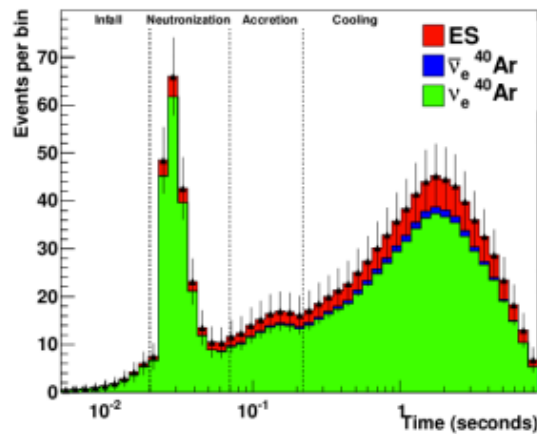
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- NuFit 2014
 - ▣ <http://www.nu-fit.org/>
 - ▣ Includes results through Neutrino 2014
- Some preference for δ_{CP} near $-\pi/2$
- θ_{23} octant unknown
- IH slightly preferred ($<1\sigma$ significance)
- Further constraints expected from existing and planned experiments:
 - ▣ See talks in “3ν mixing” session tomorrow morning
 - ▣ External constraints on mixing angles improve early sensitivity of ELBNF
 - ▣ Measurements or even hints of MH or δ_{CP} value could influence ELBNF run plan

Underground Physics Example: SNB Neutrinos

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Supernova burst neutrinos
(10 kpc, 40 kt LArTPC)

- SN neutrinos have energies order 10 MeV
- Detector requirements to be demonstrated:
 - ▣ Low threshold: ~ 5 MeV
 - ▣ Energy resolution: $\sim 11\%/\sqrt{E[\text{MeV}]} \oplus 2\%$
 - ▣ Timing resolution requirements:
 - \sim few ms event-by-event to observe neutronization burst
 - 1 s burst timing to provide early alert
 - ▣ Angular resolution and ES detection required for pointing to SN location
- ▣ Tagging of de-excitation γ from ν_e absorption
- ▣ Background (cosmogenic radioactivity & intrinsic detector contamination) sufficiently low
- ▣ Efficient triggering on a SN burst

Other physics topics (nucleon decay, atmospheric neutrinos, NP oscillations) will each have their own requirements.

Sociology



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- The intermediate neutrino program consists of a large number of collaborations
 - ▣ Most have their own physics goals
 - ▣ Many have common hardware/software
 - ▣ Many intend to provide input to ELBNF
- How to facilitate effective communication?
 - ▣ Timely propagation of information suggests that this needs to occur outside of the formal publication process
 - ▣ Process for releasing information to another collaboration needs to be simple and clear-cut
 - ▣ Interests of individual collaborations must also be respected
- Some suggestions
 - ▣ Workshops (WINP 2016, 2017... ?)
 - ▣ Shared document database
 - ▣ Procedure within each collaboration for release of information to neutrino community
 - Similar to publication process, but with somewhat lower threshold of completeness
 - ▣ Agreement among collaborations about acknowledgment of data/results and privacy with respect to release outside the neutrino community

Summary

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- Current data already constraining long-baseline oscillation parameters
- Multitude of existing and upcoming LAr TPC experiments/prototypes/test beam detectors provide opportunities to acquire experience and data that will benefit long-baseline neutrino oscillation measurements at LBNF
 - ▣ Cross-section measurements
 - ▣ Calibration/detector-response data
 - ▣ Characterization of background
 - ▣ Validation of simulations
 - ▣ Development of analysis techniques
 - ▣ Refinement of detector designs
 - ▣ Many separate experiments offers opportunity to test cross-calibration and extrapolation from one detector to another
- Coordination to facilitate efficient use of resources and effective communication among experiments will be critical
- R&D for (larger/better/cheaper) future detectors must continue

Note: Intermediate neutrino program experiments are also pursuing physics measurements!